LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

LLNL-TR-455702

Photonuclear Physics and Data Evaluations

D. Brown, J. Gronberg, J. Verbeke, D. Wright

September 17, 2010

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Photonuclear physics and data evaluations

David Brown, Jeff Gronberg, Jerome Verbeke, Doug Wright
Lawrence Livermore National Laboratory

September 15, 2010
UCRL-TR-455702

Abstract

We present a brief outline of the basic physics of photon induced nuclear reactions and describe the history and current content of modern photonuclear databases.

Contents

List of Figures

List of Tables

1 Photonuclear physics

A photonuclear interaction begins with the absorption of a photon by a nucleus, leaving the nucleus in an excited state. The nucleus then undergoes multiple de-excitation processes emitting secondary particles and possibly undergoing fission. There are two main mechanisms for photon absorption by a nucleus: the giant dipole resonance (relevant for photon energies in the range 12-16 MeV) and quasi-deuteron absorption (relevant for energies < 150 MeV). For photon energies below about 2 MeV there is also a relatively weak process: Nuclear Resonance Fluorescence (NRF). In this process the photon induces a magnetic dipole vibrational resonance of the nucleus. It is about a hundred times weaker than the giant dipole resonance and is extremely narrow, on the order a few keV. The key feature is that it produces characteristic, i.e. isotope dependent, gamma-ray emission lines.

The giant dipole resonance can be viewed as an electromagnetic wave (photon) inducing an electric dipole-like vibrational resonance of the nucleus as a whole, which results in a collective excitation of the nucleus. The giant dipole resonance occurs with highest probability when the wavelength of the photon is comparable to the size of the nucleus. This typically occurs for photon energies in the range of 12 to 16 MeV and has a resonance width of a few MeV. For energies above 16 MeV, photons are mostly absorbed through the quasi-deuteron absorption process. Here the incident photon interacts with the dipole moment of a correlated neutron-proton pair inside the target nucleus.

Once the photon has been absorbed by the nucleus, single or multiple particle emission can occur. For energies below 150 MeV, a combination of gamma-rays, neutrons, protons, deuterons, tritons, helium-3 particles, alphas and fission fragments can be emitted. The threshold for the production of a given secondary particle is governed by the separation energy of that particle, which is typically a few MeV up to 10's of MeV. Most of these particles are emitted via pre-equilibrium and equilibrium mechanisms.

Pre-equilibrium emission occurs when a particle within the nucleus receives a large amount of energy from the absorption mechanism and escapes the binding force of the nucleus after at least one, but very few, interactions with other particles. This process occurs on a fast time scale compared to equilibrium emission.

Equilibrium emission can be viewed as particle evaporation. This process typically occurs after the available energy has been distributed among the nucleons. In the classical sense, particles boil out of the nucleus as they penetrate the nuclear potential barrier. For heavy elements, evaporation neutrons are emitted preferentially (versus charged particles, such as protons, deuterons, alphas, etc.) as they are not subject to the Coulomb barrier. After these initial emissions, the nucleus is still in an excited state, and will relax to the ground state by the emission of one or more gamma-rays.

Fission is often modeled as a form of evaporation, and it occurs at roughly the same time scale (i.e. it competes with equilibrium emission but occurs after pre-equilibrium emission), however it is a completely separate kind of process. Fission is viewed as a mostly adiabatic distortion of a highly deformed nucleus. The fission process results in two fragments. For each parent nucleus, there is a relatively broad distribution of possible daughter fragment combinations. Each daughter nucleus can then undergo further decay.

The various de-excitation processes (pre-equilibrium emission, equilibrium emission, and individual fission) have decay widths in the the range 0.01 MeV up to 10 MeV, which corresponds to very short decay times of 0.1 ps down to 10^{-23} seconds. In multiplying materials, where neutrons from one fission event trigger fission elsewhere in the material, there is an additional time structure due to the transport time and thermalization time of the secondary neutrons. For fission chains this results in times of a few ns up to μs for the output of particles after the initial, primary fission.

2 Photonuclear data evaluations

In the mid 1990's a research coordination project was formed under the auspices of the International Atomic Energy Agency (IAEA) to collect all relevant experimental photonuclear data and to release a library of evaluated data files covering major isotopes of importance to structural, shielding, activation analysis, fission, and transmutation applications [1]. The two main goals were:

1. Review and choose the highest quality photonuclear data available at that time, taking from the Korean Atomic Energy Institute (KAERI), the Japanese Atomic Energy Institute (JENDL), a collaboration between IPPE/Obninsk and CDFE/Moscow (BOFOD, Russia), the Chinese Nuclear Data Center (CNDC) and the Los Alamos National Laboratory (LANL) libraries;

2. Develop new evaluations for important nuclei not covered by other libraries.

As part of this coordinated effort, the LANL Nuclear Theory and Applications group (T-2) produced a series of photonuclear evaluations for the Accelerator Production of Tritium (APT) project. These were released in 1999 as the LANL150u nuclear data library [2, 3, 4, 5].

In 2000 the complete IAEA photonuclear library [6] was released and it contains all of the LANL150u library. In 2006 the US nuclear data program produced a new photonuclear data library as part of ENDF/B-VII.0 [7]. There is substantial overlap between evaluations among these libraries: the ENDF/B-VII.0 photonuclear library was taken almost entirely from the IAEA photonuclear library, adding ^{240}Pu and ^{241}Am and improving 22 other isotopes. The actinides that were improved for ENDF/B-VII.0 now contain prompt and delayed fission neutron spectra. Table 1 (on page 10) lists all of the photonuclear evaluations in the ENDF/B-VII.0 library and indicates which isotopes were modified from the original IAEA photonuclear library. This table also shows which evaluations are taken from the LANL150u library.

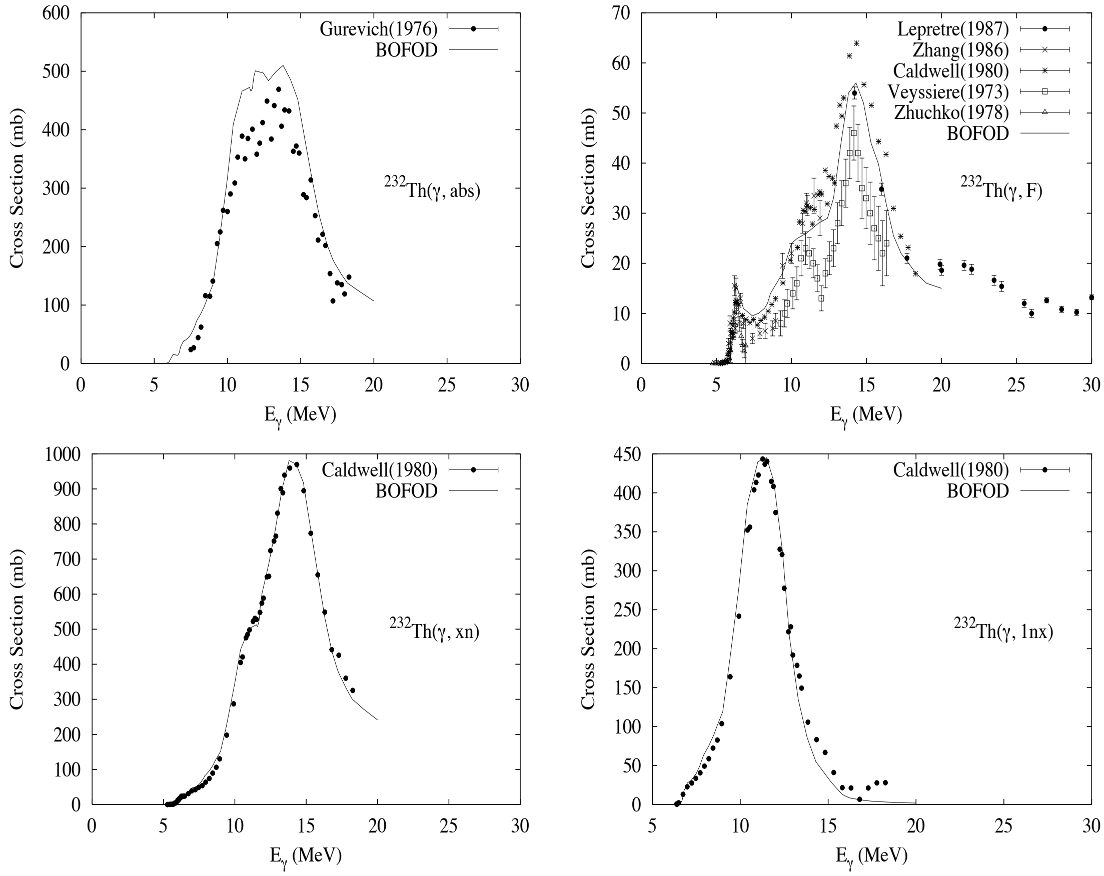
A few examples of the input data and resulting evaluation (in this case BOFOD) are given in Figures 1-4 in which we show the main cross sections for ^{232}Th, ^{235}U, ^{238}U and ^{239}Pu from [6]. In figure 5, we show the $\bar{\nu}$ evaluation added to the ENDF/B-VII.0 library. While the cross sections shown are the cross sections from the IAEA photonuclear library, they were unchanged in the ENDF/B-VII.0 library. One should note from these plots that the cross section evaluations stop at 20 MeV incident γ energy, even in cases where there is data available above this energy. In fact, all evaluations from the BOFOD library (^{232}Th, $^{233-238}$U, ^{237}Np and $^{238-241}$Pu) stop at 20 MeV whereas the rest of the library extends to 140-150 MeV, depending on the isotope. This is a real feature of both the IAEA photonuclear and ENDF/B-VII.0 libraries, i.e. photofission artificially and incorrectly "turns off" at 20 MeV.

The TENDL-2009 [8] library, produced by the Nuclear Research and Consultancy Group (NRG) in the Netherlends, takes a very different approach. The library is produced by tuning some of the inputs to the TALYS Hauser-Feshbach model in an attempt to reproduce *all* available neutron incident cross section data. This results in good agreement with some isotopes and discrepancies of up to a factor of two for others. The same input parameters are then used in the model to calculate photonuclear cross sections, but no comparison with data have been done. The library contains photonuclear cross sections for all stable isotopes and isotopes with half-life greater than 1 second (resulting in 1164 isotopes in the photonuclear sublibrary). This library is available from the TALYS website[1] and is transport code ready. All of the TENDL-2009 photonuclear evaluations end at 30 MeV. In Fig. 6 we show the ^{235}U(n,f) cross section comparing ENDF/B-VII.0 and TENDL-2009.

[1] http://www.talys.eu/tendl-2009/

$\gamma + {}^{232}\mathbf{Th}$

Abundance	Threshold Energies (MeV)								
(%)	γ,n	γ,p	γ,t	γ,He-3	γ,α	γ,2n	γ,np	γ,2p	γ,3n
100.00	6.44	7.75	10.41	12.15	-4.08	11.56	13.31	13.25	18.35

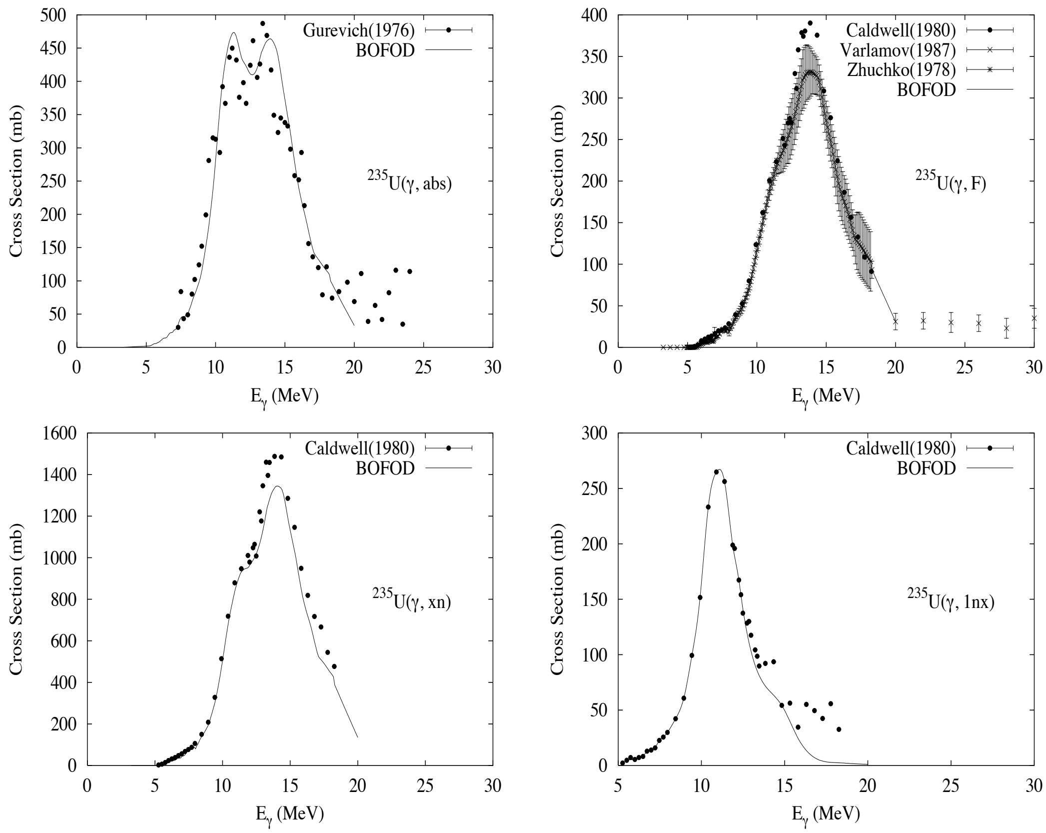


Experimental information is available for the photoabsorption [Gur76], photofission [Vey73, Cal80a, Zha86, Zhu78b, Lep87], and (γ, xn), (γ, 1nx), and (γ, 2nx) cross sections [Cal80a, Vey73]. For a complete reference list of photofission cross sections see [Blo99a]. The photofission cross section presents large differences between some of the important measurements, in the energy range below 10 MeV. In the GDR range there are systematical differences between the Livermore [Cal80a] and the Saclay data [Vey73]. The evaluation adopted the Saclay data for photoneutron production as reference, in order to obtain the relevant parameters of the statistical model [Blo99b]. The widths for radiative, neutron and fission decays were taken from the description of the photofission cross section below 6 MeV [Sto97]. The calculated results are in good agreement with the experimental data for (γ, xn), ((γ, 1nx) and (γ, 2nx) reactions [Cal80a].

Figure 1: Summary of photonuclear cross-sections for ^{232}Th from ref. [6].

$\gamma + {}^{235}\mathbf{U}$

Abundance	Threshold Energies (MeV)								
(%)	γ,n	γ,p	γ,t	γ,He-3	γ,α	γ,2n	γ,np	γ,2p	γ,3n
0.72	5.30	6.71	9.96	9.46	-4.68	12.14	11.93	12.39	17.89

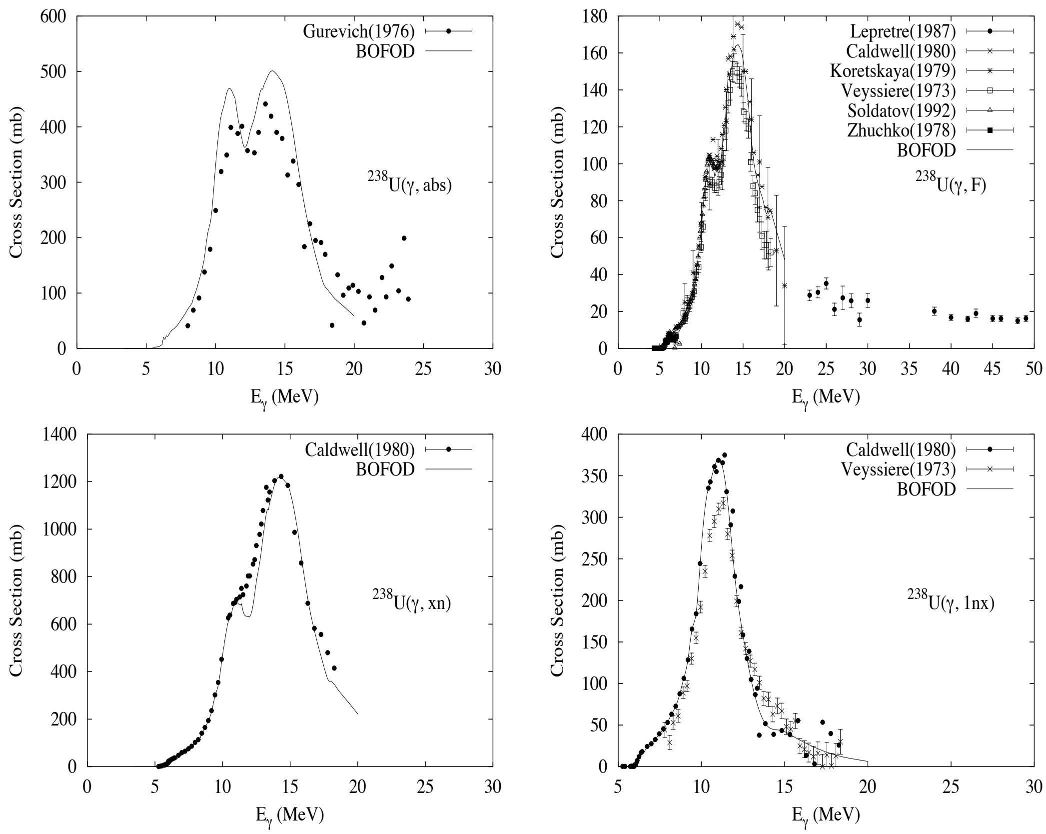


Experimental information is available for the photoabsorption [Gur76], photofission [Cal80b, Cal80a, Zhu78b], (γ, xn), and (γ, 1nx) cross sections [Cal80a]. For a complete reference list of photofission cross sections see [Blo99a]. The evaluation adopted the Caldwell's data for the (γ, 1nx), and Varlamov's photofission data as reference below 14 MeV, in order to obtain the relevant parameters of the statistical model [Blo99b]. The widths for radiative, neutron and fission decays were taken from the description of the (γ, 1nx) cross section below 14 MeV [Cal80a].

Figure 2: Summary of photonuclear cross-sections for ^{235}U from ref. [6].

$\gamma + {}^{238}\mathrm{U}$

Abundance	Threshold Energies (MeV)								
(%)	γ,n	γ,p	γ,t	γ,He-3	γ,α	γ,2n	γ,np	γ,2p	γ,3n
99.27	6.15	7.62	9.97	11.88	-4.27	11.28	13.39	13.01	17.82

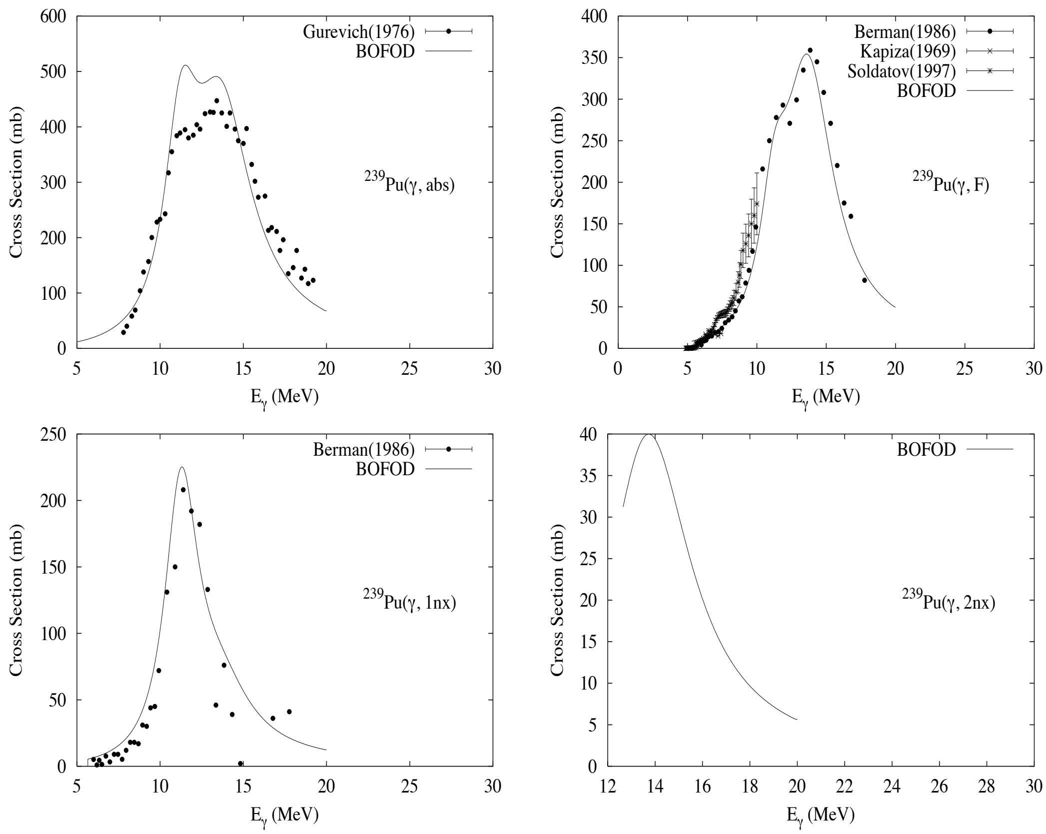


Experimental information is available for the photoabsorption [Gur76], photofission [Vey73, Cal80b, Cal80a, Zhu78b, Sol92], and (γ, xn), (γ, 1nx), and (γ, 2nx) cross sections [Cal80a, Vey73]. For a complete reference list of reaction cross sections see [Blo99a]. The evaluation adopted the Livermore data for (γ, 1nx) and (γ, xn) [Cal80a], and both the Livermore and Obninsk data for photofission [Cal80a] and [Sol92] as reference below 14 MeV, in order to obtain the relevant parameters of the statistical model [Blo99b]. The widths for radiative, neutron and fission decays were taken from the description of the(γ, 1nx) cross section below 14 MeV [Cal80a], and the photofission cross section below 10 MeV [Sol92]. In general, the results are in reasonable agreement with experimental data [Gur76] for photoabsorption cross section and for (γ,xn), (γ,1nx), (γ,2nx) and (γ,F) reactions for gamma-ray energy below 20 MeV.

Figure 3: Summary of photonuclear cross-sections for ^{238}U from ref. [6].

$\gamma + {}^{239}\mathbf{Pu}$

Abundance	Threshold Energies (MeV)								
(%)	γ,n	γ,p	γ,t	γ,He-3	γ,α	γ,2n	γ,np	γ,2p	γ,3n
0.00	5.65	6.16	9.74	8.79	-5.24	12.65	11.64	11.38	18.51



Experimental information is available for the photoabsorption [Gur76], photofission ([Ber86, Zhu78b, Sol92], and (γ, xn), (γ, 1nx), and (γ, 2nx) cross sections [Ber86]. For a complete reference list of photofission cross sections see [Blo99a]. The evaluation adopted the Livermore data for photoneutron production as reference, in order to obtain the relevant parameters of the statistical model [Blo99b]. The widths for radiative, neutron and fission decays were taken from the description of the photofission cross section below 10 MeV [Sol92].

Figure 4: Summary of photonuclear cross-sections for ^{239}Pu from ref. [6].

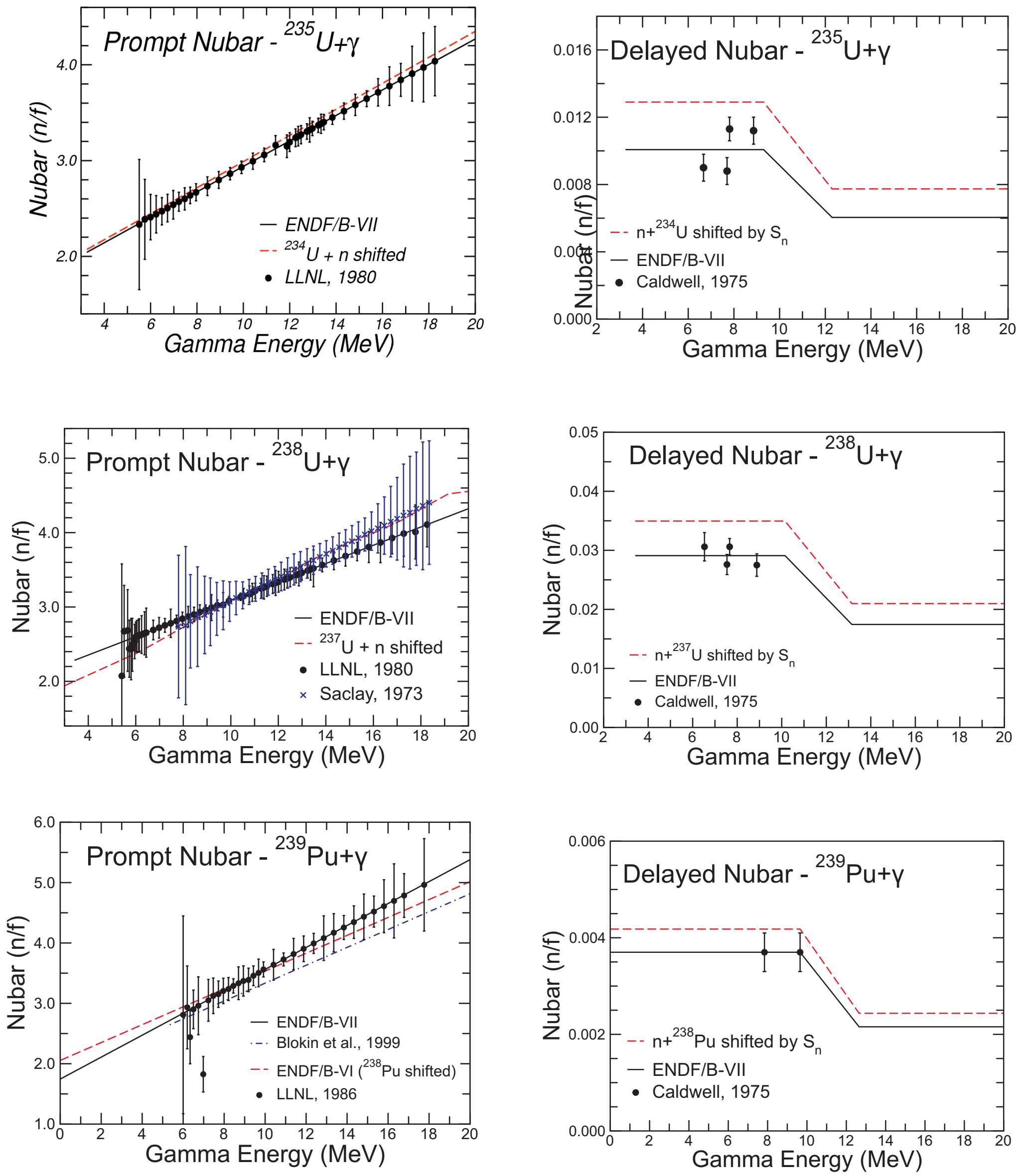


Figure 5: Summary of prompt and delayed $\bar{\nu}$ data added to the major actinides in the ENDF/B-VII.0 library [7].

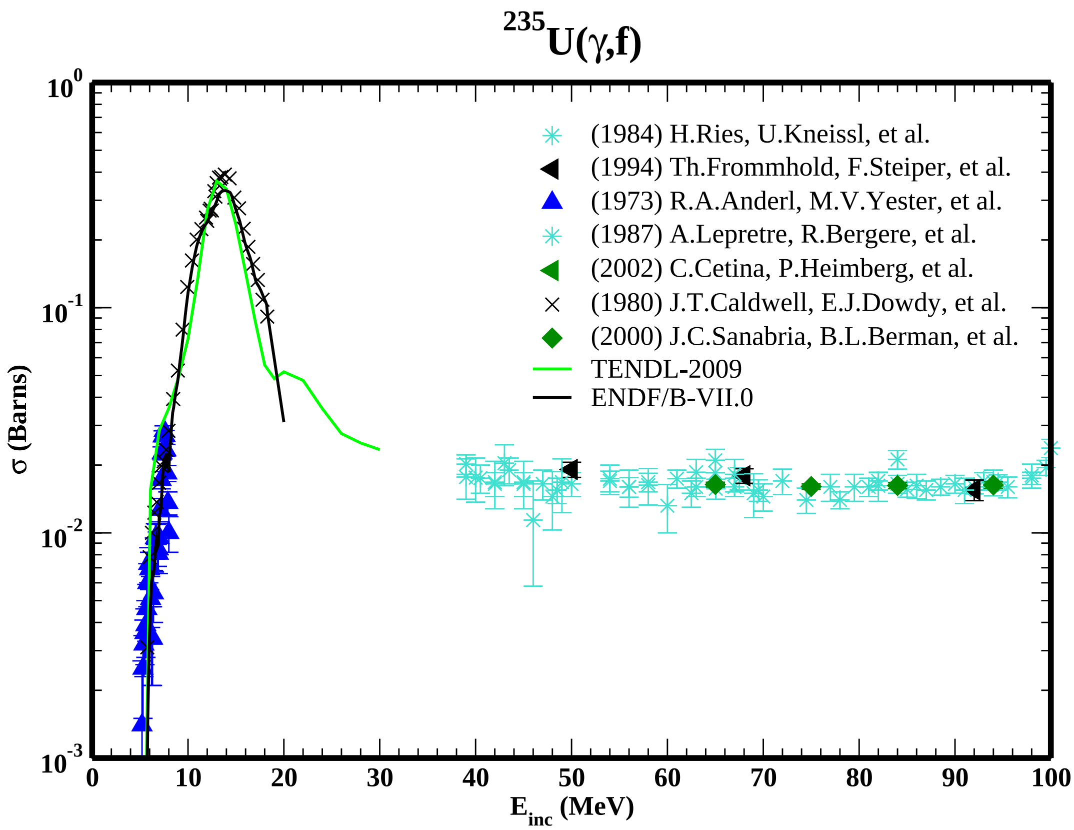


Figure 6: Summary of photo-fission cross-sections for ^{235}U from experimental data and the ENDF/B-VII.0 and TENDL-2009 nuclear data libraries.

Table 1: Contents of the photonuclear sublibrary of the **ENDF/B-VII.0** nuclear data library. As most of these evaluations were taken from the IAEA Photonuclear Library, modified ones are footnoted and the original evaluation from the IAEA Photonuclear Library is stated in the footnote. Only Th, U, Np, Pu, and Am have photofission data and are marked as such with an asterisk in the target name.

Target	Authors	Source Library	Date
^{2}H	G. Hale	ENDF/B-VII.0	Jan. 2005 [2]
^{9}Be	B. Yu, J. Zhang, Y. Han	CENDL/G	Dec. 1998
^{12}C	M. Chadwick, P. Young	LANL150u	Oct. 1999
^{13}C	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{14}N	Han, Lee, Oblozinsky, Chadwick	ENDF/B-VII.0	Dec. 1999 [3]
^{15}N	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{16}O	M. Chadwick, P. Young	LANL150u	Nov. 1999
^{17}O	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{18}O	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{23}Na	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{24}Mg	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{25}Mg	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{26}Mg	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{27}Al	M. Chadwick, P. Young	LANL150u	Dec. 1999
^{28}Si	M. Chadwick, P. Young	ENDF/B-VII.0	Nov. 1999 [4]
^{29}Si	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{30}Si	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{32}S	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{33}S	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{34}S	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{36}S	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{35}Cl	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{37}Cl	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{36}Ar	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{38}Ar	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{40}Ar	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{40}Ca	M. Chadwick, P. Young	LANL150u	Dec. 1998
^{42}Ca	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{43}Ca	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{44}Ca	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{46}Ca	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{48}Ca	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{46}Ti	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{47}Ti	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{48}Ti	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999

[2] Replaces T. Murata, JENDL High Energy File, JAERI, Aug. 1995.
[3] Replaces T. Murata, JENDL High Energy File, JAERI, Aug. 1995.
[4] Replaces Y. Han, Y.-O. Lee, KAERI/G-1, KAERI, Dec. 1999.

Target	Authors	Source Library	Date
^{49}Ti	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{50}Ti	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{51}V	B. Yu, Y, Han, J. Zhang	CENDL/G	Apr. 1998
^{50}Cr	Y. Han, Y.-O. Lee	ENDF/B-VII.0	Dec. 1999 [5]
^{52}Cr	Y. Han, Y.-O. Lee	ENDF/B-VII.0	Dec. 1999 [6]
^{53}Cr	Y. Han, Y.-O. Lee	ENDF/B-VII.0	Dec. 1999 [7]
^{54}Cr	Y. Han, Y.-O. Lee	ENDF/B-VII.0	Dec. 1999 [8]
^{55}Mn	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{54}Fe	Y. Han, Y.-O. Lee	ENDF/B-VII.0	Dec. 1999 [9]
^{56}Fe	M. Chadwick, P. Young	ENDF/B-VII.0	Sep. 1998 [10]
^{57}Fe	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{58}Fe	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{59}Co	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{58}Ni	Y. Han, Y.-O. Lee	ENDF/B-VII.0	Dec. 1999 [11]
^{60}Ni	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{61}Ni	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{62}Ni	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{64}Ni	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{63}Cu	M. Chadwick, P. Young	LANL150u	Dec. 1999
^{65}Cu	Y. Han, Y.-O. Lee	ENDF/B-VII.0	Dec. 1999 [12]
^{64}Zn	Y. Han, Y.-O. Lee	ENDF/B-VII.0	Dec. 1999 [13]
^{66}Zn	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{67}Zn	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{68}Zn	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{70}Zn	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{70}Ge	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{72}Ge	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{73}Ge	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{74}Ge	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{76}Ge	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{84}Sr	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{86}Sr	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{87}Sr	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{88}Sr	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{90}Sr	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{90}Zr	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999

[5] Replaces B. Yu, Y. Han, J. Zhang, CENDL/G, CNDC, Oct. 1998.
[6] Replaces Y. Han, B. Yu, J. Zhang, CENDL/G, CNDC, Oct. 1998.
[7] Replaces Y. Han, B. Yu, J. Zhang, CENDL/G, CNDC, Oct. 1998.
[8] Replaces Y. Han, B. Yu, J. Zhang, CENDL/G, CNDC, Oct. 1998.
[9] Replaces Lee Samyol, M. Igashira, N. Kishida, JENDL High Energy File, JAERI, Mar. 1995
[10] Replaces Lee Samyol, M. Igashira, N. Kishida, JENDL High Energy File, JAERI, Mar. 1995.
[11] Replaces N. Kishida, JENDL High Energy File, JAERI, Mar. 1995
[12] Replaces N. Kishida, JENDL High Energy File, JEARI, Oct. 1999
[13] Replaces N. Kishida, JENDL High Energy File, JEARI, Mar. 1995

Target	Authors	Source Library	Date
^{91}Zr	Y. Han, Y.-O. Lee	ENDF/B-VII.0	Dec. 1999 [14]
^{92}Zr	Y. Han, Y.-O. Lee	ENDF/B-VII.0	Dec. 1999 [15]
^{93}Zr	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{94}Zr	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{96}Zr	Y. Han, Y.-O. Lee	ENDF/B-VII.0	Dec. 1999 [16]
^{93}Nb	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{94}Nb	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{92}Mo	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{94}Mo	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{95}Mo	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{96}Mo	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{97}Mo	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{98}Mo	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{100}Mo	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{102}Pd	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{104}Pd	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{105}Pd	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{106}Pd	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{107}Pd	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{108}Pd	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{110}Pd	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{107}Ag	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{108}Ag	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{109}Ag	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{106}Cd	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{108}Cd	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{110}Cd	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{111}Cd	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{112}Cd	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{113}Cd	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{114}Cd	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{116}Cd	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{112}Sn	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{114}Sn	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{115}Sn	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{116}Sn	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{117}Sn	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{118}Sn	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{119}Sn	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{120}Sn	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{122}Sn	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999

[14] Replaces B. Yu, Y, Han, J. Zhang, CENDL/G, CNDC, Mar. 1998.
[15] Replaces B. Yu, Y, Han, J. Zhang, CENDL/G, CNDC, Mar. 1998.
[16] Replaces B. Yu, Y, Han, J. Zhang, CENDL/G, CNDC, Mar. 1998.

Target	Authors	Source Library	Date
^{124}Sn	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{121}Sb	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{123}Sb	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{120}Te	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{122}Te	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{123}Te	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{124}Te	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{125}Te	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{126}Te	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{128}Te	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{130}Te	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{127}I	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{129}I	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{133}Cs	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{135}Cs	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{137}Cs	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{141}Pr	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{144}Sm	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{147}Sm	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{148}Sm	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{149}Sm	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{150}Sm	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{151}Sm	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{152}Sm	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{154}Sm	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{158}Tb	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{159}Tb	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{165}Ho	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{181}Ta	M. Chadwick, P. Young	ENDF/B-VII.0	Apr. 1999 [17]
^{180}W	B. Yu, Y, Han, J. Zhang	CENDL/G	Dec. 1997
^{182}W	B. Yu, Y, Han, J. Zhang	ENDF/B-VII.0	Dec. 1997 [18]
^{183}W	B. Yu, Y, Han, J. Zhang	CENDL/G	Dec. 1997
^{184}W	M. Chadwick, P. Young	LANL150u	Apr. 1998
^{186}W	B. Yu, Y, Han, J. Zhang	ENDF/B-VII.0	Dec. 1997 [19]
^{197}Au	Y. Han, Y.-O. Lee	KAERI/G-1	Dec. 1999
^{206}Pb	M. Chadwick, P. Young	LANL150u	Dec. 1998
^{207}Pb	M. Chadwick, P. Young	LANL150u	Dec. 1998
^{208}Pb	M. Chadwick, P. Young	LANL150u	Sep. 1998
^{209}Bi	Y. Han, Y.-O. Lee	ENDF/B-VII.0	Dec. 1999 [20]

[17] Replaces Y. Lee, J. Chang, T. Fukahori, JENDL High Energy File, JAERI, Dec. 1997.
[18] Replaces T. Asami, JENDL High Energy File, JAERI, Jun. 1996
[19] Replaces T. Asami And N. Kishida, JENDL High Energy File, JAERI, Dec. 1999
[20] Replaces B. Yu, Y. Han, CENDL/G, CNDC, Oct. 1998.

Target	Authors	Source Library	Date
^{232}Th*	Blokhin A. I., et al.	BOFOD-98	Feb. 1998
^{233}U*	Blokhin A. I., et al.	BOFOD-98	Feb. 1998
^{234}U*	Blokhin A. I., et al.	BOFOD	Feb. 1999
^{235}U*	M. Giacri, D. Ridikas, M. Chadwick	ENDF/B-VII.0	Aug. 2005 [21]
^{236}U*	Blokhin A. I., et al.	BOFOD	Feb. 1999
^{238}U*	M. Giacri, D. Ridikas, M. Chadwick	ENDF/B-VII.0	Aug. 2005 [22]
^{237}Np*	M. Giacri, D. Ridikas, M. Chadwick	ENDF/B-VII.0	Aug. 2005
^{238}Pu*	Blokhin A. I., et al.	BOFOD	Feb. 1999
^{239}Pu*	M. Giacri, D. Ridikas, M. Chadwick	ENDF/B-VII.0	Nov. 2005 [23]
^{240}Pu*	M. Giacri, D. Ridikas, M. Chadwick	ENDF/B-VII.0	Jun. 2005 [24]
^{241}Pu*	Blokhin A. I., et al.	BOFOD	Feb. 1999
^{241}Am*	M. Giacri, D. Ridikas, M. Chadwick	ENDF/B-VII.0	Sep. 2005 [25]

*Has photofission data.

[21] Replaces Blokhin A. I., et al., BOFOD-90, CJD, Oct. 1990. Delayed $\bar{\nu}$ data added by LANL.
[22] Replaces Blokhin A. I., et al., BOFOD-98, CJD, Feb. 1998. Delayed $\bar{\nu}$ data added by LANL.
[23] Replaces Blokhin A. I., et al., BOFOD, CJD, Feb. 1999. Delayed $\bar{\nu}$ data added by LANL.
[24] The IAEA photonuclear library does not contain this isotope.
[25] The IAEA photonuclear library does not contain this isotope.

References

[1] "Summary Report of the 2^{nd} Research Coordination Meeting on Compilation and Evaluation of Photonuclear Data for Applications," International Atomic Energy Agency Report INDC(NDS)-384, Vienna, Austria (1998).

[2] M. B. Chadwick, "Neutron, proton, and photonuclear cross-sections for radiation therapy and radiation protection," Radiat. Environ. Biophys. 37, pp. 235242 (1998)

[3] M.B. Chadwick et al., "Cross-Section Evaluations to 150 MeV for Accelerator-Driven Systems and Implementation in MCNPX," *Nuclear Science and Engineering,* **131,** pp. 293-328 (1999).

[4] M. B. Chadwick, P. G. Young, R. E. MacFarlane, M. C. White and R. C. Little, "Photonuclear physics in radiation transport: I. Cross sections and spectra photonuclear cross section evaluations to 150 MeV," Nucl. Sci. Eng. 144, pp. 157173 (2003).

[5] M. C. White "Release of the LA150U Photonuclear Data Library," Los Alamos National Laboratory memo X-5:MCW-00-87(U), Los Alamos, NM (2000).

[6] P. Obložinský, ed. "Handbook of photonuclear data for applications: Cross sections and spectra," International Atomic Energy Association report IAEA-TECDOC-1178, Vienna, Austria (2000).

[7] M.B. Chadwick, P. Obložinský, M. Herman, N.M. Greene, R.D. McKnight, D.L. Smith, P.G. Young, R.E. MacFarlane, G.M. Hale, S.C. Frankle, A.C. Kahler, T. Kawano, R.C. Little, D.G. Madland, P. Moller, R.D. Mosteller, P.R. Page, P. Talou, H. Trellue, M.C. White, W.B. Wilson, R. Arcilla, C.L.Dunford, S.F. Mughabghab, B. Pritychenko, D. Rochman, A.A. Sonzogni, C.R. Lubitz, T.H. Trumbull, J.P. Weinman, D.A. Brown, D.E. Cullen, D.P. Heinrichs, D.P. McNabb, H. Derrien, M.E. Dunn, N.M. Larson, L.C. Leal, A.D. Carlson, R.C. Block, J.B. Briggs, E.T. Cheng, H.C. Huria, M.L. Zerkle, K.S. Kozier, A. Courcelle, V. Pronyaev and S.C. van der Marck, "ENDF/B-VII.0: Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology," *Nuclear Data Sheets*, **1**07, pp. 2931-3060 (2006), ISSN 0090-3752, DOI: 10.1016/j.nds.2006.11.001, (`http://www.sciencedirect.com/science/article/B6WNV-4MGDW8W-1/2/5040b3d5640d1c334634e9f83c754893`).

[8] A. Koning and D. Rochman, "TENDL-2009: Consistent TALYS-based Evaluated Nuclear Data Library including covariance data", JEFF DOC 1310, (2009); available at `http://www.talys.eu/tendl-2009/`.